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A concurrent solution for intra-cell flow path layouts and I/O point locations of cells in a cellular manufacturing system ☆

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ABSTRACT

In this paper, we study the I/O (Input/Output) point location problem and the intra-cell flow path layout problem of cells in a cellular manufacturing system. Traditional approaches have often solved these two problems as separate problems, despite they are mutually affected. As a result, the results obtained by traditional approaches may not be as desirable as expected. In this study, we propose a layout procedure that can solve these two problems concurrently, so that the sum of the inter-cell flow distance and the intra-cell flow distance can be minimized. We assume cells have been arranged along a straight-line inter-cell flow path. Furthermore, the machines' positions on each cell's intra-cell flow path have been determined, but the intra-cell flow path of each cell has not been placed on the shop floor yet. We also assume the configuration of intra-cell flow paths is serpentine. The proposed layout procedure classifies the flow distance incurred by inter-cell flow into five types and minimizes them with different solution procedures containing various linear programming models. The proposed layout procedure has four phases. At the first phase, we find each cell's input and output points on the inter-cell flow path by considering only the inter-cell flow distance. At the second phase, we find the input and outpoint points on each cell's intra-cell flow path by considering only the intra-cell flow distance. At the third phase, we use the points found in the previous two phases as references to help us correctly orient and arrange each cell's intra-cell flow path on the shop floor. Finally, at the fourth phase, we find the accurate the input points and output points on each cell's intra-cell flow path and the inter-cell flow path by simultaneously considering the inter-cell and the intra-cell flow distance. We use an example to illustrate the proposed layout procedure. The results of the example show that the proposed layout procedure can effectively find each cell's I/O point locations and intra-cell flow path layout by considering both intra-cell and inter-cell flow distance at the same time.

1. Introduction

The problem environment of this paper is a cellular manufacturing system, in which parts follow predetermined flow paths to move around. The flow distance of a cellular manufacturing system is incurred by two types of flow – inter-cell and intra-cell. The amount of inter-cell and intra-cell flow of each cell is determined by the cell formation design. And, the flow distance of these two types of flow is determined by the system's various layout designs, e.g. the layout of cells, the layout of inter-cell flow path, the layout of machines in each cell, the layout of intra-cell flow path connecting machines within each cell, and the location of each cell's I/O (Input/Output) points. In this study, we focus on two layout problems – the intra-cell flow path layout problem within each cell and the problem of locating each cell's I/O points. Traditional approaches often treat these two problems as separate problems and solve them individually and independently. However, as one will see, these two problems are mutually affected, thus solving them individually and independently may not result in best solutions. This can be realized from the example in Fig. 1. Let us assume M has been determined as the best I/O point for the cell in Fig. 1a. However, if one rearranges the cell's intra-cell flow path (without changing the positions of machines on the intra-cell flow path) to generate a new intra-cell layout as shown in Fig. 1b, then M may no longer be the best I/O point for the cell. Compared with the cell in Fig. 1a, the cell in Fig. 1b needs a longer flow path segment to connect the intra-cell flow path with the inter-cell flow path at M. A longer flow path segment implies a greater intra-cell flow distance for the cell in Fig. 1b. When the inter-cell flow occurs, it incurs more than inter-cell flow distance. For example, as is shown in Fig. 2, in order for a part P (at a machine N in a cell 1) to visit another machine R in another cell 2, five types of flow distance will be incurred.

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Nomenclature

- *BSD*(*p*) the minimum distance between a cell *p*'s intra-cell flow path segment and its cell border
- *MSD*(*p*) the minimum distance between a cell *p*'s two neighboring parallel intra-cell flow path segments
- *CW*(*p*) the width of a cell *p*
- *CL*(*p*) the length of a cell *p*
- *IB*(*p*) the input point found on a cell *p*'s inter-cell flow path at Phase I
- *OB*(*p*) the output point found on a cell *p*'s inter-cell flow path at Phase I
- *LB*(*p*) the lower bound point of a cell *p* on the inter-cell flow path
- *UB*(*p*) the upper bound point of a cell *p* on the inter-cell flow path
- *LSB*(*p*) the lower bound point of a cell *p* on the inter-cell flow path with the consideration of *BSD*(*p*)
- *USB*(*p*) the upper bound point of a cell *p* on the inter-cell flow path with the consideration of *BSD*(*p*)
- *CS* the set of cells in the system
- $D_{i,j}$ the travel distance from *i* to *j*
- $F_{i,j}$ the flow from *i* to *j*
- PW_i the position of a point *i* on the intra-cell flow path of a cell in the system
- PB_i the position of a point *i* on the inter-cell flow path
- *MS*(*p*) the set of machines in a cell *p*
- *IW*(*p*) the input point at which parts enter a cell *p*'s intra-cell flow path by considering only the Type-E flow distance
- *OW*(*p*) the output point at which parts leave a cell *p*'s intra-cell flow path by considering only the Type-A flow distance
- *FIW*(*p*) the amount of flow entering the *IW*(*p*) of a cell *p*
- *FOW*(*p*) the amount of flow leaving the *OW*(*p*) of a cell *p*
- *LNTH*(*p*) the length of the intra-cell flow path in a cell *p*
- *B* the beginning point of an intra-cell flow path in a cell *p*
- *E* the ending point of an intra-cell flow path in a cell *p*
- *OldPB*(*p*,*i*) the position value of *i* on *p*'s intra-cell flow path before the exchange of the intra-cell flow path's beginning point and the ending point in Section 4.3.2
- *N1*(*p*) the number of complete H-segments in *SEG1*(*p*)
- *N2*(*p*) the number of complete H-segments in *SEG2*(*p*)
- *N3*(*p*) the number of complete H-segments in *SEG3*(*p*)
- *N*(*p*) the number of complete V-segments in the intra-cell flow path segment starting from *IBP*(*p*) or *OBP*(*p*) (depending on whichever is smaller) to the ending point E in Arrangements I–IV
- *N1_BIG*(*p*) the maximum possible number of complete H-segments in *SEG1*(*p*)
- *N2_BIG*(*p*) the maximum possible number of complete H-segments in *SEG2*(*p*)
- *N3_BIG*(*p*) the maximum possible number of complete H-segments in *SEG3*(*p*)
- *N_BIG*(*p*) the maximum possible number of complete V-segments in $(CW(p) - 2BSD(p))/MSD(p)$
- *SEG1*(*p*) the segment between *LSB*(*p*) and *IB*(*p*) (if $PB_{OB(p)} \geqslant PB_{IB(p)}$) or the segment between *LSB*(*p*) and *OB*(*p*) (if $PB_{IB(p)} > PB_{OB(p)}$) in an up-and-down serpentine layout
- *SEG2*(*p*) the segment between *IB*(*p*) and *OB*(*p*) in an up-and-down serpentine layout
- *SEG3*(*p*) the segment between *OB*(*p*) and *USB*(*p*) (if $PB_{OB(p)} \geqslant PB_{IB(p)}$) or the segment between *IB*(*p*) and *USB*(*p*) (if $PB_{IB(p)} > PB_{OB(p)}$) in an up-and-down serpentine layout
- *IBP*(*p*) the projected point of *IB*(*p*) on a cell *p*'s intra-cell flow path
- *OBP*(*p*) the projected point of *OB*(*p*) on a cell *p*'s intra-cell flow path
- *H*(*p*) the length of a complete H-segment in a cell *p*
- *V*(*p*) the length of a complete V-segment in a cell *p*
- *S1*(*p*) the vertical distance from a cell *p*'s south boundary to its nearest H-segment in an up-and-down serpentine layout
- *S2*(*p*) the vertical distance from a cell *p*'s north boundary to its nearest H-segment in an up-and-down serpentine layout
- *L1*(*p*) the horizontal distance from *IB*(*p*) (if $PB_{OB(p)} \geqslant PB_{IB(p)}$) or *OB*(*p*) (if $PB_{IB(p)} > PB_{OB(p)}$) to the nearest V-segment on its right in an up-and-down serpentine layout
- *L2*(*p*) the horizontal distance from *IB*(*p*) (if $PB_{OB(p)} \geqslant PB_{IB(p)}$) or *OB*(*p*) (if $PB_{IB(p)} > PB_{OB(p)}$) to the nearest V-segment on its left in an up-and-down serpentine layout
- *L3*(*p*) the horizontal distance from *LSB*(*p*) to the nearest V-segment on its right in an up-and-down serpentine layout
- *R1*(*p*) the horizontal distance from *OB*(*p*) (if $PB_{OB(p)} \geqslant PB_{IB(p)}$) or *IB*(*p*) (if $PB_{IB(p)} > PB_{OB(p)}$) to the nearest V-segment on its left in an up-and-down serpentine layout
- *R2*(*p*) the horizontal distance from *OB*(*p*) (if $PB_{OB(p)} \geqslant PB_{IB(p)}$) or *IB*(*p*) (if $PB_{IB(p)} > PB_{OB(p)}$) to the nearest V-segment on its right in an up-and-down serpentine layout
- *R3*(*p*) the horizontal distance from *USB*(*p*) to the nearest V-segment on its left in an up-and-down serpentine layout
- *T1*(*p*) the horizontal distance from a cell *p*'s west boundary to the nearest V-segment in a left-and-right serpentine layout
- *T2*(*p*) the horizontal distance from a cell *p*'s east boundary to the nearest V-segment in a left-and-right serpentine layout
- *T3*(*p*) *T3*(*p*) is equal to the vertical distance from a cell *p*'s south boundary to the nearest H-segment that contains *IBP*(*p*) or *OBP*(*p*) minus *BSD*(*p*) in a left-and-right serpentine layout
- *T4*(*p*) *T4*(*p*) is equal to the vertical distance from a cell *p*'s north boundary to its nearest H-segment minus *BSD*(*p*) in a left-and-right serpentine layout
- *C*(*p*) the horizontal distance between *IB*(*p*) and *OB*(*p*) in a left-and-right serpentine layout
- *DISLB*(*p*) the horizontal distance from *IB*(*p*) (if $PB_{OB(p)} \geqslant PB_{IB(p)}$) or *OB*(*p*) (if $PB_{IB(p)} > PB_{OB(p)}$) to a cell *p*'s west boundary in a left-and-right serpentine layout
- *DISUB*(*p*) the horizontal distance from *OB*(*p*) (if $PB_{OB(p)} \geqslant PB_{IB(p)}$) or *IB*(*p*) (if $PB_{IB(p)} > PB_{OB(p)}$) to a cell *p*'s east boundary in a left-and-right serpentine layout
- *GIB*(*p*) a cell *p*'s input point (on the inter-cell flow path) that is found at Phase IV
- *GOB*(*p*) a cell *p*'s output point (on the inter-cell flow path) that is found at Phase IV
- *GIW*(*p*) the projected point of a cell *p*'s *GIB*(*p*) on the cell's intra-cell flow path
- *GOW*(*p*) the projected point of a cell *p*'s *GOB*(*p*) on the cell's intra-cell flow path
- *LIB*(*p*) the lower bound point of *IB*(*p*) on the inter-cell flow path
- *UIB*(*p*) the upper bound point of *IB*(*p*) on the inter-cell flow path
- *LOB*(*p*) the lower bound point of *OB*(*p*) on the inter-cell flow path
- *UOB*(*p*) the upper bound point of *OB*(*p*) on the inter-cell flow path
- *LBGIB*(*p*) the lower bound point of *GIB*(*p*) on the inter-cell flow path